RESTRICTED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 936

PLASTIC MOUNTINGS FOR AIRCRAFT WINDSHIELDS

By Kathryn H. Bradley and B. M. Axilrod
National Bureau of Standards

Washington
May 1944

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SUMMARY

Several laminated glass windshields, all characterized by an extension of the center plastic layer around the edges of the panels for mounting in aircraft, have been investigated to determine their suitability for use in airplanes with pressurized cabins. The various constructions of the extended portions of the windshields which serve for mounting purposes included plastic alone, plastic and one sheet of glass extended, plastic extension reinforced with an aluminum strip, and plastic extension reinforced with a steel strip. The tests conducted on the various windshield panels included creep, behavior under cyclic loading, and bursting tests at temperatures of -20°, 77°, and 140° F.

The results of the tests indicated that the laminated windshields with plastic-mounting extensions reinforced by aluminum or steel were resistant to creep and bursting at pressures of the order that will be encountered in service. It appears that their ability to withstand service pressures at a temperature of 140° F should make them suitable for use in a heat de-icing design which involves double glazing and the circulation of heated air in the space between the two glass panes.

INTRODUCTION

In the construction of airplanes with pressure-sealed cabins the problem of finding suitable means for mounting the glass windshields and windows arises. The mounting must furnish an airtight seal over a wide range of temperatures, must allow for differential thermal expansion of the windshield relative to the frame without the creation of high stresses in the glass, and must not be so flexible that the windshield deflects excessively under possible service conditions. To meet these requirements, several mountings have been proposed in which the plastic layer of the laminated glass is extended beyond the edge of the glass, the windshield being held in place by bolts through the extended plastic edge.

In order to evaluate mountings of this type, the National Bureau of Standards, at the request and with the financial assistance of the National Advisory Committee for Aeronautics, carried out an investigation of several types of plastic mounting. The deflection characteristics, creep behavior, and bursting strength at various temperatures were included in this work. This report summarizes the results of the investigation.

MATERIALS AND EQUIPMENT

The laminated glass windshields, supplied by the Pittsburgh Plate Glass Company, consisted of a layer of 0.12-inch-thick vinyl butyral plastic sandwiched between 12-inch square sheets of 7/64-inch-thick semi-tempered glass. In these windshields the plastic inner layer was extended, sometimes with reinforcement, to form the mounting. The mountings tested, illustrated in figure 1, were constructed as follows:

Type	Description
A	Plastic extended
B	Plastic extended and one sheet of glass partially extended
C	Plastic extended and reinforced with a strip of 0.032-inch-thick aluminum reaching from the outer edge of the plastic to about 1/4 inch between the glass plates
D	Plastic extended and reinforced with a strip of 0.019-inch-thick stainless steel reaching from the outer edge of the plastic to about 1/4 inch between the glass plates

The windshield panels were tested in a heavy steel pressure chamber. The mountings were clamped to the chamber by means of a frame which was bolted to the chamber as shown in figure 2. A pressure chamber with a windshield panel in place and a dismantled pressure chamber are shown in figures 3 and 4, respectively. The surfaces of the chamber and of the frame adjacent to the windshield were ground flat to minimize leaks. It was found in some preliminary tests that at some temperatures a frame of 1/4-inch-thick steel would twist measurably at moderate pressures. Since measurements of deflection were made with reference to the frame, it was decided to use frames 1/2 inch in thickness or greater for the subsequent work. The steel pressure chambers were erected so that the plane of the windshield was vertical for all tests.

It was found that the most satisfactory method for maintaining constant pressure on the windshield in the test chamber was by means of compressed oxygen or air in a cylinder equipped with a two-stage regulator. With such equipment, a constant pressure could be maintained over long periods of time and for a wide range of temperatures. All tests were made with the same temperature on both sides of the windshield. The temperatures at which tests were conducted were 140°, 77°, and -20° F. The deflection of the panels was measured at the center, at each corner, and at the middle of each edge. The deflection measurements at the corners and the middle of the edges were made at a distance of about 1/8 inch from the inside edge of the frame. A dial gage mounted on a bar the edges of which were machined flat was used for all deflection measurements except those taken at 140° F, when the dimensions of the oven necessitated the use of a screw micrometer depth gage at the corners and the middle of the edges.

TEST PROCEDURES

Procedure for Creep Tests

Each windshield panel was clamped firmly in the test chamber and conditioned at the test temperature for at least 16 hours prior to testing. The test consisted of maintaining a constant pressure in the test chamber for a period of 24 hours. Deflection measurements were taken at time intervals that were approximately logarithmically equal, both for the 24-hour loading period and the subsequent 24 hours of recovery; the first set of readings was taken about 5 minutes after the pressure was applied. Since a set of measurements for all the locations required several minutes, the values for the four corners (or the middle of the edges) could not be averaged in the early part of a test because of the high rate of creep. The data for each position were plotted and curves were drawn for the first 2 hours of each loading and each recovery period. The average creep for four equivalent positions for a particular time interval was obtained from these curves.

In some instances, owing to the development of leaks, failure of control apparatus, and so forth, it was necessary to use the same windshield panel for more than one test. An appreciable time was allowed between tests to provide for recovery so that any effect of the prior tests on these panels would be negligible.

Procedure for Cyclic Loading Tests

These tests, carried out at 77° F, were intended to approximate the loading and unloading sequence for an airplane making daily flights with daily servicing periods included. The mean temperature in a windshield panel in an airplane in normal high altitude flight probably would be considerably less than 77° F, and hence the amount of creep and "permanent" set obtained in service would be less than that obtained in these tests. If heated air for de-icing purposes is circulated against the inside surface of the windshield, the mean temperature in the windshield may be much greater than 77° F. In the latter case, a plastic mounting with a higher softening temperature than that of those tested may be required to avoid excessive creep and permanent set.

The windshield panels were subjected in alternate periods to a constant pressure of 8 pounds per square inch for 8 hours and then to 16 hours of recovery. The panels were given 4 to 7 cycles of loading. Deflection readings at the center, middle of the edges, and corners were taken at the end of each loading and each recovery period.

Procedure for Bursting Strength Tests

The bursting strength tests were made at temperatures of approximately -20°, 77°, and 140° F upon panels which had been conditioned 17 to 24 hours. In the short-time tests the pressure was increased gradually to cause failure in about 1 to 2 minutes. The panels were mounted and the bolts tightened at room temperature, after which the specimens were removed to the conditioning atmosphere. For the tests performed at 77° and 140° F, it was not necessary to tighten the bolts again before the pressure was applied. At -20° F, however, seven of the eight panels tested leaked so badly that tightening again at the low temperature was necessary before the tests could be made. From this behavior it is apparent that either a gasket material must be included in the mounting or the mounting must be redesigned to prevent leaks resulting from the contraction of the windshield panel at low temperature.

To obtain strength-time curves for each temperature and each type of panel, considerable time as well as a large amount of material would be required. Consequently, it was decided to subject two types of panel to two-thirds of the maximum pressure which they withstood in the short-time bursting tests to obtain some data on their long-time bursting strength. Types A and C panels were selected for these tests since A appeared to be the least satisfactory and C the most satisfactory in the other tests. The panels were conditioned and mounted as described for the cyclic loading test.

RESULTS AND DISCUSSION

Creep Tests

The deflection-time characteristics for the various types of panel are shown in figures 5 to 14. The 5-minute and the 24-hour deflection values for these panels are given in table I. The difference between the 5-minute and the 24-hour deflection value, the amount of creep for that time interval, was calculated for the panels reported in table I. These creep data are presented in table II.

Creep at -20° F.- All the windshields were quite rigid at the temperature of -20° F. The deflections at the center did not exceed 0.04 inch for pressures of 6 to 10 pounds per square inch. For the same pressures the deflections at the edges were at most a few thousandths of an inch. The creep at sub-zero temperatures was negligible, amounting to not more than 0.002 inch at the center, which is about the order of accuracy of the low-temperature measurements.

Creep at 77° F.- At a temperature of 77° F and a pressure of 8 pounds per square inch the deflections observed for all panels were much greater than at -20° F. At the center, initial deflections ranging from 0.15 to 0.24 inch were observed. For the middle of the edge, the lowest deflections were exhibited by the mountings containing a metal insert, the values being 0.018 and 0.013 inch for types C and D, respectively. The type B panel, in which the load on the plastic at the edge is mainly compression rather than shear, deflected about twice as much at the middle of the edge as the types C and D. At the same position a deflection of 0.08 inch was noted for the type A mounting. The initial corner deflections did not exceed a hundredth of an inch for all types.

It can be seen in figures 10 and 11 that slight negative deflections of the corners of panels C and D were obtained in these tests. These negative corner deflections may be explained as follows: When a square plate is uniformly loaded, the corners in general have a tendency to rise (see reference 1, p. 92.) This occurs in panels both with and without the metal insert, but in the second type the panel as a whole moves considerably relative to the frame because the plastic edge deflects easily under a shearing load. The deflection is measured relative to the frame and, if the average shear deflection of the edge is high, the tendency of the corner to rise relative to the middle of the edge is not evidenced.

The creep in the 24-hour period was greatest for the type A mounting. The deflections at the center and at the middle of the edge increased almost 0.1 inch; at the corners the creep was 0.04 inch. For the other panels the amount of creep at the center ranged from 0.012 to 0.026 inch for types B, C, and D, and at the middle of the edges the creep amounted to about 0.010

inch for those panels. At the corners the creep was 0.003 inch for type B and about -0.004 inch for types C and D.

The recovery of the mountings B, C, and D was good in these tests. Since the creep for type A was several times as great as that for the other types, it is not surprising to note that a much larger residual deflection was obtained for the type A panel at the end of the 24-hour recovery period than for the other types. If the residual deflection at the end of 24 hours (table I) is compared with the amount of creep (table II), it is noted that, for all types of mounting, the residual deflection at the end of 24 hours is about half the amount of creep for the center and the middle of edge positions.

<u>Creep at 140° F.</u>- At 140° F and under a pressure of 2½ pounds per square inch, the type A mounting deflected beyond the edge of the frame in 1½ hours and failed in about 4 hours. This type would not be suitable if, when searching for leaks in the airplane cabin, this pressure were applied at high temperatures as in the tropics. The other mountings withstood the same pressure for the 24-hour period and exhibited initial center deflections of 0.07 to 0.10 inch. The deflections at the middle of the edge ranged from 0.01 inch for type C to 0.03 inch for type B. The amount of creep in 24 hours was greatest for the type B panel, but the creep at the center and the middle of the edges was only 0.03 inch. The least amount of creep was exhibited by panel C-1, which also showed the least initial deflection.

The slight differences between the deflections and the creep behavior for panels of types C and D are probably caused by slight variations in size and squareness of the panels. The deflection is sensitive to the clearance a in figure 2, and the dimensions of the glass panels vary as much as 1/32 inch.

The recovery for the panels with the metal insert was better than that for type B panel.

Cyclic Loading Tests

The deflection values for the panels tested under cyclic loading are presented in table III and are depicted graphically in figures 15 through 18. A comparison of the behavior of duplicate panels of the four types of windshield after 8 hours of continuous loading at a pressure of 8 pounds per square inch is given in table IV.

Types B, C, and D panels showed only very slight increases in deflection for all positions at the end of the sixth period of loading (table III), the amount being less than 0.001 inch for type B, less than 0.005 inch for type C, and less than 0.002 inch for type D. Panel A-14, however, after four periods of loading showed a minimum increase in deflection of 0.03 inch and failed $1\frac{1}{2}$ hours after the start of the fifth period of loading.

The recovery of types B, C, and D panels in these tests was satisfactory, although the deflection after each period of recovery was slightly greater than the corresponding quantity for the preceding period. After 6 cycles the deflection at the end of the recovery period was not greater than 0.01 inch for any of the three types and for all the locations. The corresponding quantity was 0.05 to 0.08 inch for panel A-14 after only 4 cycles.

Since the panels vary in their dimensions as much as 1/32 inch, the results of tests made on similar types of panels may vary somewhat. Other factors possibly affecting the test results are the clamping pressure, the aging of the panels, and the variation between lots. With regard to the variation between lots, the panels tested were from two lots, those numbered 1 through 4 being in the first group and the remainder in the second. The panels were 1 to 9 months old at the time they were tested. While no detailed study was made of the variation to be expected in consequence of these factors, some data are available for panels tested at 77° F for creep and cyclic loading. (See table IV.) It is evident from these data that panels of types B, C, and D are less affected by variations between specimens or in experimental conditions than panels of type A.

Bursting-Strength Tests

The results of the short-time bursting-strength tests are presented in table V. The appearance of representative panels after this test is illustrated in figures 19 to 23. The data obtained in burst tests made under long-time loading conditions are presented in table VI.

The bursting pressure for the type A panels in the short-time test varied from 10 pounds per square inch at 140° F to 64 pounds per square inch at -20° F. (See table V.) At the higher temperature the panel failed by a combination of shearing and tearing of the plastic around the edges rather than by fracture of the glass. The B type panel, which was somewhat stronger at the high temperature but not at the sub-zero temperature, failed over a pressure range of 20 to 34 pounds per square inch. The C and D panels are much alike in construction and are superior to the others in bursting strength. They failed at pressures ranging from 20 pounds per square inch at 140° F to 70 pounds per square inch at -20° F. At 77° F these two types were characterized by a failure of the glass at about 30 pounds per square inch followed by a failure of the plastic at slightly higher pressure. Types C and D panels deflected greatly after the glass failed at 77° and 140° F; a typical failure from a test made at 77° F is shown in figure 23.

In the "long-time" burst tests, type A and type C panels withstood pressures of 38 and 43 pounds per square inch, respectively, at sub-freezing temperatures without failure for more than 7 hours. The A type panel failed at 77° and 140° F at pressures of 20 and 7.3 pounds per square inch, respectively, within a few minutes. A type C panel withstood the test pressure, 20.5 pounds per square inch, for almost 2 hours at 77° F, but another C panel failed quickly when subjected to a temperature of 140° F at 17.5 pounds per square inch pressure. Since the panels with the metal insert were found superior to the other types, an additional test was made at 140° F upon a type C panel with a pressure of 8 pounds per square inch. This pressure did not cause failure of the panel in a period of 6 hours.

CONCLUDING REMARKS

Of the several windshields with an extended plastic layer for mounting in aircraft that were investigated, those having a strip of 0.032-inch-thick aluminum or 0.019-inch-thick stainless steel inserted in the plastic layer from the outer edge to about 1/4 inch between the glass plates proved to be superior in the various tests. These windshields were resistant to creep and bursting under pressure conditions of the order of those which are encountered in service. Their ability to withstand ordinary service pressures at a temperature of 140° F should make them suitable for use in a heat-de-icing design that involves double glazing and the circulation of heated air in the space between the two glass panes.

The research indicated that some difficulty may be encountered with leaks when windshields with these types of mounting are subjected to low temperatures unless the frames are tightened after being exposed to low temperature or some device is employed to maintain pressure on the frames at all times.

National Bureau of Standards,
Washington, D. C., March 30, 1944.

REFERENCE

1. Timoshenko, Stephen: Theory of Plates and Shells. McGraw-Hill Book Co., Inc., 1940.

TABLE I. CREEP TESTS ON WINDSHIELD MOUNTINGS AT VARIOUS TEMPERATURES.

Specimen Number	Type of Mounting	Conditions of Test: Temperature	Conditions of Test: Pressure	Deflections during loading period: Corner: After 5 min	Corner: After 24 hr	Middle of Edge: After 5 min	Middle of Edge: After 24 hr	Center: After 5 min	Center: After 24 hr	Deflections during recovery period: Corner: After 5 min	Corner: After 24 hr	Middle of Edge: After 5 min	Middle of Edge: After 24 hr	Center: After 5 min	Center: After 24 hr
		°F.	lb/in²	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
A-3[a]	Plastic	-20	6	001	0	.001	.001	.015	.017	-	-	-	-	-	-
B-1	Plastic-Glass	-20	10	0	0	.004	.004	.033	.033	0	0	.001	0	.002	0
C-1[b]	Plastic-Aluminum	-20	10	0	0	.001	.001	.023	.025	-	-	-	-	.005	0
D	Plastic-Steel	-20	Not tested												
A-12	Plastic	77	5	.001	.040	.077	.152	.234	.323	.044	.013	.122	.032	.166	.043
B-2	Plastic-Glass	77	5	.006	.009	.044	.052	.211	.223	.005	.002	.023	.003	.041	.005
C-2	Plastic-Aluminum	77	5	-.007	-.011	.018	.031	.163	.188	-.006	-.005	.015	.004	.036	.011
D-12	Plastic-Steel	77	5	-.004	-.007	.013	.023	.155	.181	-.003	0	.018	.008	.035	.009
A-11	Plastic	140	2.5	Deflected beyond edge of frame within 1-1/2 hrs; failed after 4-1/4 hrs.											
B-2[c]	Plastic-Glass	140	2.5	.004	.017	.030	.060	.101	.131	-.002	.002	.043	.020	.048	.024
C-1	Plastic-Aluminum	140	2.5	-.003	-.003	.009	.021	.089	.089	0	0	.012	.004	.019	.008
D-2	Plastic-Steel	140	2.5	-.004	.001	.021	.048	.089	.120	.005	.002	.029	.010	.034	.012

[a]This windshield had been subjected to a pressure of 6 lb/in² at -20°F for 7 hr on the day previous to this test. In a test about 6 weeks later it withstood a pressure of 2.5 lb/in² at 155°F. for 10 minutes before it failed.

[b]Fifteen and 3 days, respectively, previous to this test, this windshield had been subjected to tests at a pressure of 6 lb/in² at 77°F for 24 hr. The test at 140°F reported in this table was made 6 days after the test at -20°F

[c]This windshield had been subjected to a pressure of 2.5 lb/in² for 3 hrs. at 140°F, 2 days after the test at 77°F reported in this table. After 3 days of additional recovery this test was made.

TABLE II. CREEP OF WINDSHIELDS DURING LOADING PERIOD.

Specimen Number	Type of Mounting	Conditions of Test: Temperature	Conditions of Test: Pressure	Creep (Difference between Deflections at 5 min. and at 24 hours under Load): Corner	Middle of Edge	Center
		°F	lb/in^2	in.	in.	in.
A-3	Plastic	-20	6	-.001	0	.002
B-1	Plastic-Glass	-20	10	0	0	0
C-1	Plastic-Aluminum	-20	10	0	0	.002
D	Plastic-Steel	Not tested				
A-12	Plastic	77	8	.039	.075	.089
B-2	Plastic-Glass	77	8	.003	.008	.012
C-2	Plastic-Aluminum	77	8	-.004[a]	.013	.025
D-12	Plastic-Steel	77	8	-.003[a]	.010	.026
A-11	Plastic	140	2.5	failed after 4-1/4 hours		
B-2	Plastic-Glass	140	2.5	.013	.030	.030
C-1	Plastic-Aluminum	140	2.5	0	.012	.020
D-2	Plastic-Steel	140	2.5	.005	.027	.031

[a]Deflection is negative (see Table 1) and increased in magnitude.

TABLE III. CYCLIC LOADING TESTS ON WINDSHIELDS.

Specimen Number	Type of Mounting	Cycle	Deflection of Windshield — At End of 8 hr Loading Period: Center	Middle of Edge	Corner	At End of 16 hr Recovery Period: Center	Middle of Edge	Corner
			in.	in.	in.	in.	in.	in.
A-14	Plastic	1	.386	.216	.083	.041	.036	.024
		2	.410	.239	.105	.057	.050	.036
		3	.408	.241	.105	.071	.064	.046
		4		>.265[a]	.111	.082	.073	.055
		5	Failed after 1-1/2 hours of cycle No. 5					
A-4	Plastic	1	.272	.119	.019	.025	.020	.007
		2	.278	.127	.024	.037	.031	.012
		3	.290	.137	.027	.047	.040	.016
		4	.294	.149	.032			
B-3	Plastic-Glass	1	.2425	.055	.010	.002	.001	.001
		2	.2435	.0545	.0105	.004	.0025	.0015
		3	.2435	.054	.0105	.005	.0035	.0015
		4	.2415	.0545	.0105	.007	.004	.003
		5	.242	.055	.0105	.007	.0045	.002
		6	.2425	.055	.0105	.008	.005	.0025
		7	.2415	.0555	.0105	.008	.0055	.0025
C-4	Plastic-Aluminum	1	.1845	.0205	-.0055	.006	.004	-.0005
		2	.1855	.022	-.0055	.0075	.0055	-.0005
		3	.1835	.0225	-.0055	.0085	.006	-.001
		4	.185	.0235	-.006	.009	.0065	-.001
		5	.187	.0245	-.006	.0095	.0075	-.001
		6	.187	.025	-.006	.010	.008	-.001
		7	.185.5	.025	-.006	.010	.008	-.001
D-13	Plastic-Steel	1	.1815	.020	-.006	.007	.0045	0
		2	.1835	.021	-.006	.008	.0055	0
		3	.1845	.0215	-.0065	.009	.006	-.0005
		4	.183	.021	-.006	.0085	.006	0
		5	.183	.0215	-.0055	.009	.0065	0
		6	.183	.0215	-.0055	.0095	.0065	0

[a]One edge deflected beyond frame.

TABLE IV. COMPARISON OF DEFLECTION DATA FOR WINDSHIELDS OF THE SAME TYPE.

Specimen Number	Type of Mounting	Test	Deflection after 8 hours at a pressure of 8 lb/in^2 and 77°F		
			Center	Middle of Edge	Corner
			in.	in.	in.
A-12	Plastic	Creep	.302	.134	.027
A-14	"	Cyclic loading	.386	.216	.083
A-4	"	" "	.272	.119	.019
B-2	Plastic-Glass	Creep	.282	.052	.010
B-3	" "	Cyclic loading	.2425	.055	.010
C-2	Plastic-Aluminum	Creep	.186	.029	-.010
C-4	" "	Cyclic loading	.1845	.0205	-.0055
D-12	Plastic-Steel	Creep	.179	.021	-.006
D-13	" "	Cyclic loading	.1815	.020	-.006

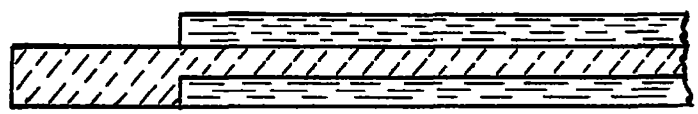
TABLE VI. RESULTS OF TESTS AT PRESSURE OF TWO-THIRDS THE BURSTING STRENGTH

Specimen Number	Type of Mounting	Temperature	Pressure	Time until Failure	Remarks
		°F	lb/in^2		
A-13	Plastic	140	7.3	2 min.	
A-15	"	77	20	5 min.	Glass failed in first two min.
A-16	"	-20	36	>7 hr	Pressure turned off after 7 hr.
C-12	Plastic-Aluminum	140	17.5	3 min.	Glass failed in first two min.
C-14	" "	140	8[a]	>6 hr	Pressure turned off after 6 hr.
C-13	" "	77	20.5	1-3/4 hr	Glass failed in 1 hr and 37 min.
C-15	" "	-20	43	>8 hr	Pressure turned off after 8 hr.

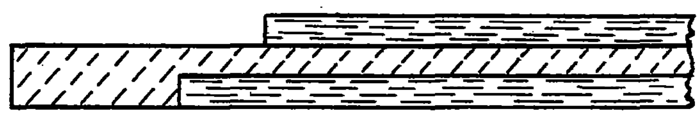
[a]Since a type C panel failed at two-thirds of the bursting strength value in 3 minutes, a test was made at the maximum working pressure.

TABLE V. RESULTS OF BURSTING STRENGTH TESTS.

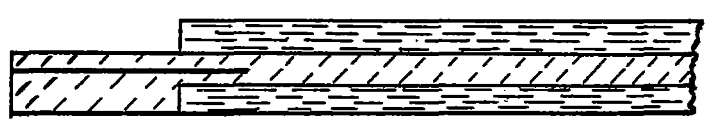
Specimen Number	Type of Mounting	Temperature	Pressure at Failure	Time to Break	Remarks
		°F.	lb/in^2	sec.	
A-5	Plastic	140	12	45	Edge failure of plastic; glass intact.
A-6	"	140	10	65	" " " " " "
A-7	"	77	29	61	Both glasses shattered
A-8	"	77	30	50	" " "
A-9	"	-20	50	90	Plastic and glass shattered.
A-10	"	-20	64	140	" " " "
B-5	Plastic-Glass	140	26	30	Inner glass only broken; plastic and outer glass intact.
B-6	" "	140	20	62	Both glasses shattered; plastic still intact.
B-8	" "	77	32.5	60	Both glasses shattered; plastic failed later at 15.5 lb/in^2.
B-9	" "	77	33	57	Both glasses shattered; plastic failed later at 17 lb/in^2.
B-10	" "	-20	30.5	67	Plastic failed later at 29 lb/in^2.
B-11	" "	-20	34	47	Both plastic and glass shattered.
C-7	Plastic-Aluminum	140	26.5	59	Both glasses broken.
C-10	" "	140	26.5	77	" " "
C-5	" "	77	30	125	Glass failed first at 29 lb/in^2.
C-6	" "	77	38	90	Glass failed first at 32 lb/in^2.
C-9	" "	-20	61	117	Both plastic and glass shattered.
C-11	" "	-20	69.5	130	" " " " "
D-8	Plastic-Steel	140	22.5	68	Both glasses broken
D-9	" "	140	20	68	" " "
D-5	" "	77	36.5	96	Glass failed first at 29 lb/in^2.
D-6	" "	77	32	99	" " " " " "
D-10	" "	-20	54	91	Both plastic and glass shattered
D-11	" "	-20	69.5	138	" " " " "



Type A

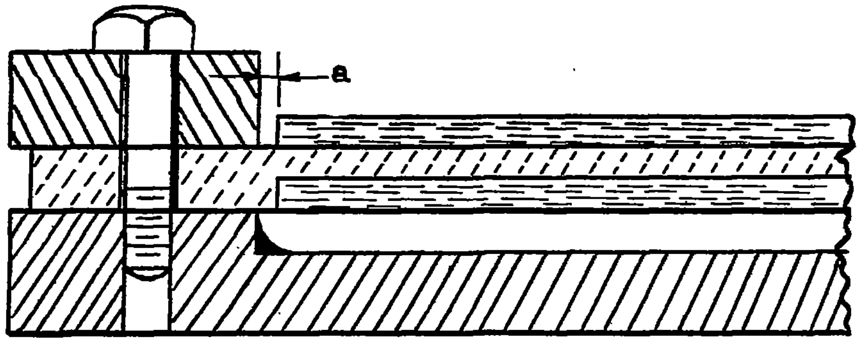


Type B



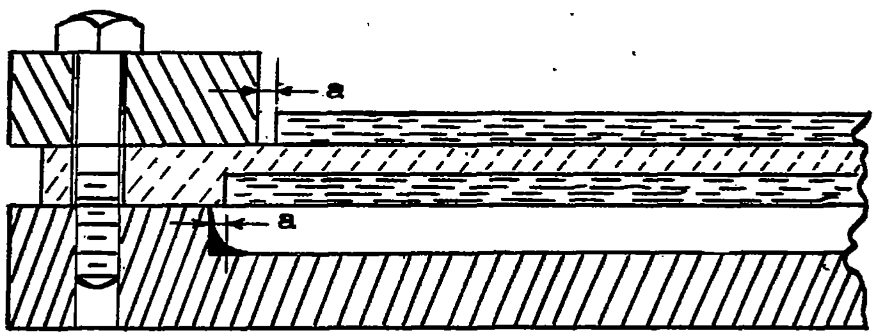
Types C and D

FIG. 1. CROSS-SECTION OF WINDSHIELD PANELS.



Types A, C, and D

Note.- Clearance a is 1/16 to 1/8 inch.



Type B

FIG. 2. CROSS-SECTION OF PRESSURE CHAMBER FOR TESTING WINDSHIELD PANELS.

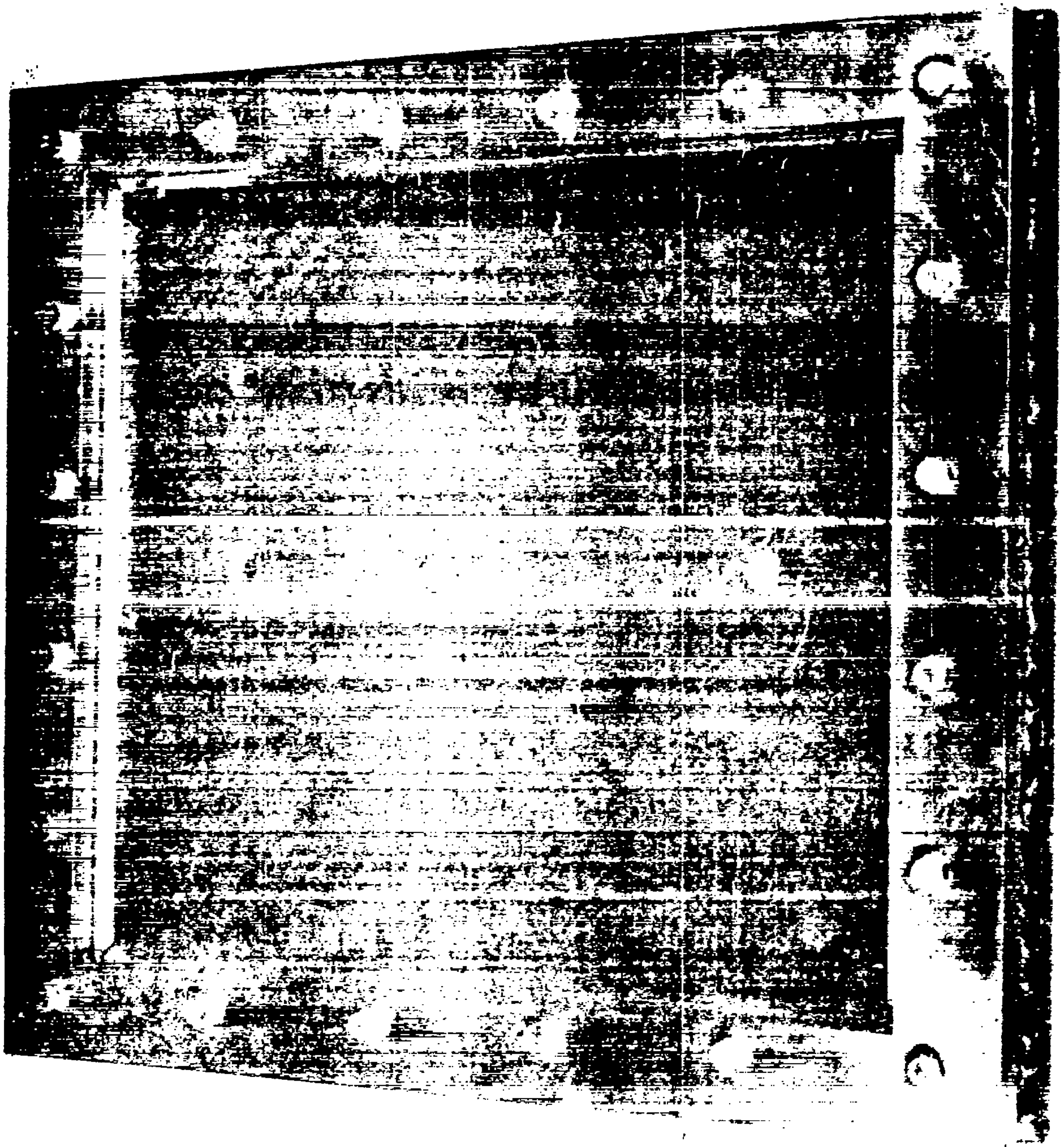


Figure 3.- Pressure chamber for types A, C, and D panels with a windshield in place.

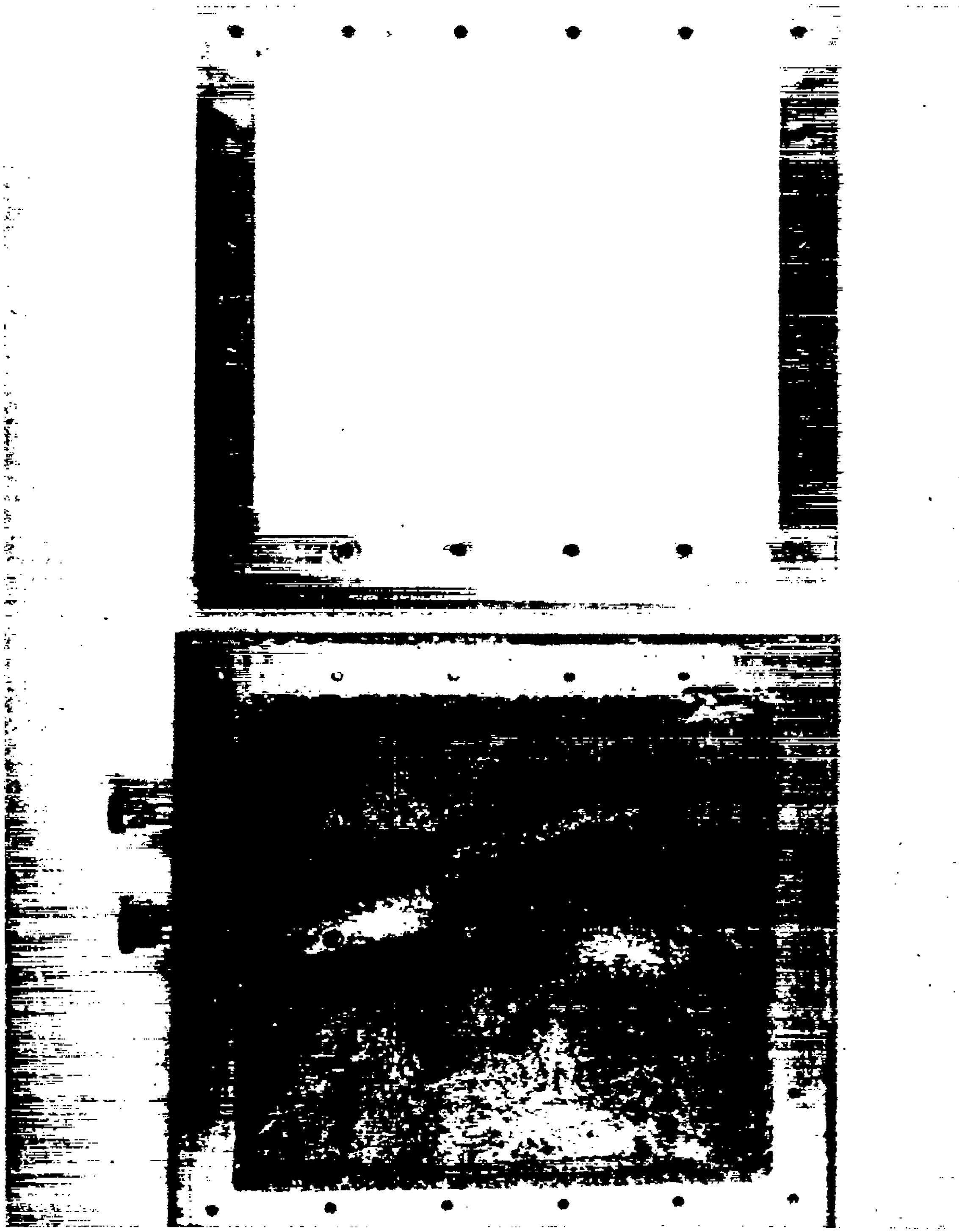


Figure 4.- Dismantled pressure chamber (same chamber as in figure 3).

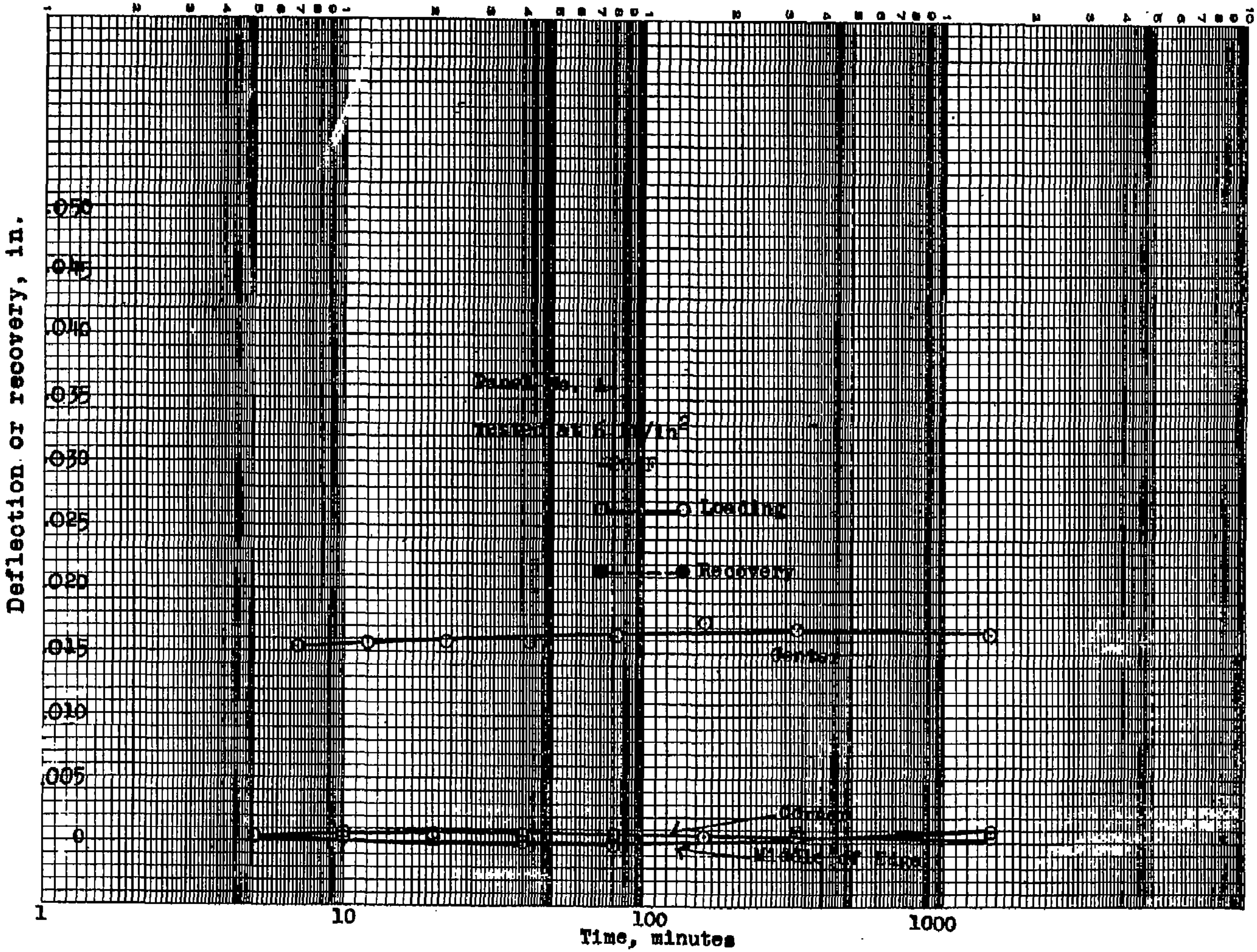


Figure 5.- Deflection-time characteristics during loading and recovery.

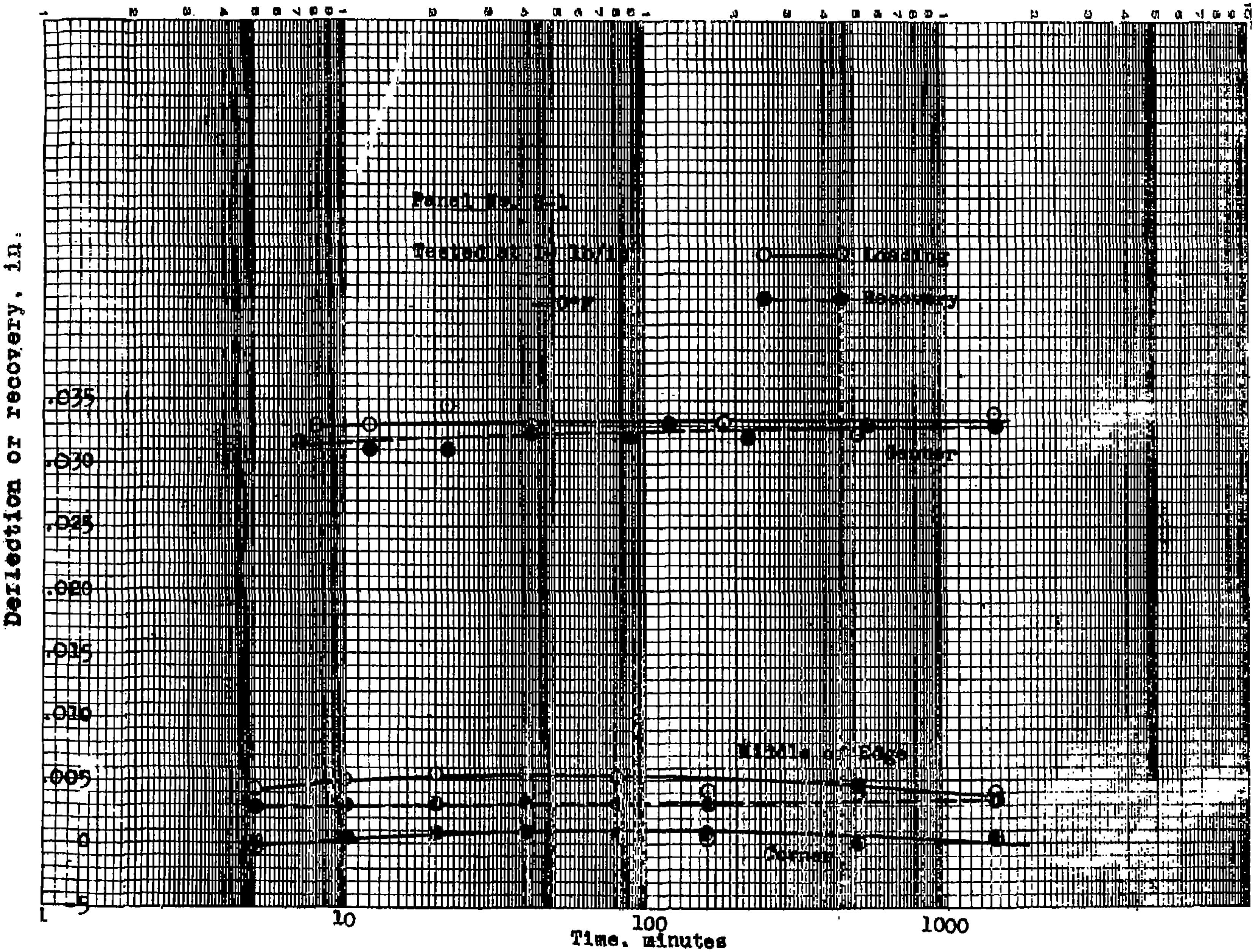


Figure 6.- Deflection-time characteristics during loading and recovery.

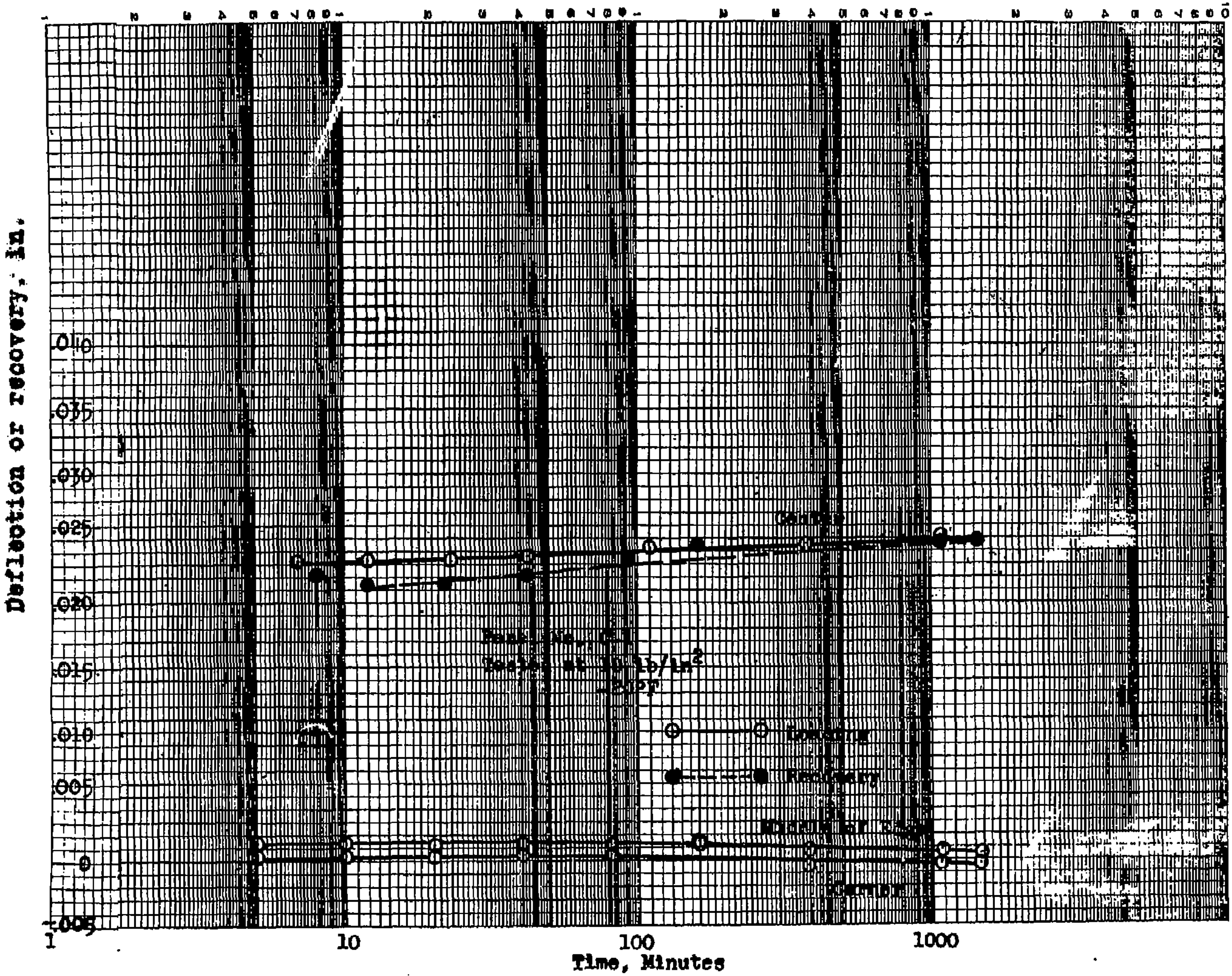


Figure 7.- Deflection-time characteristics during loading and recovery.

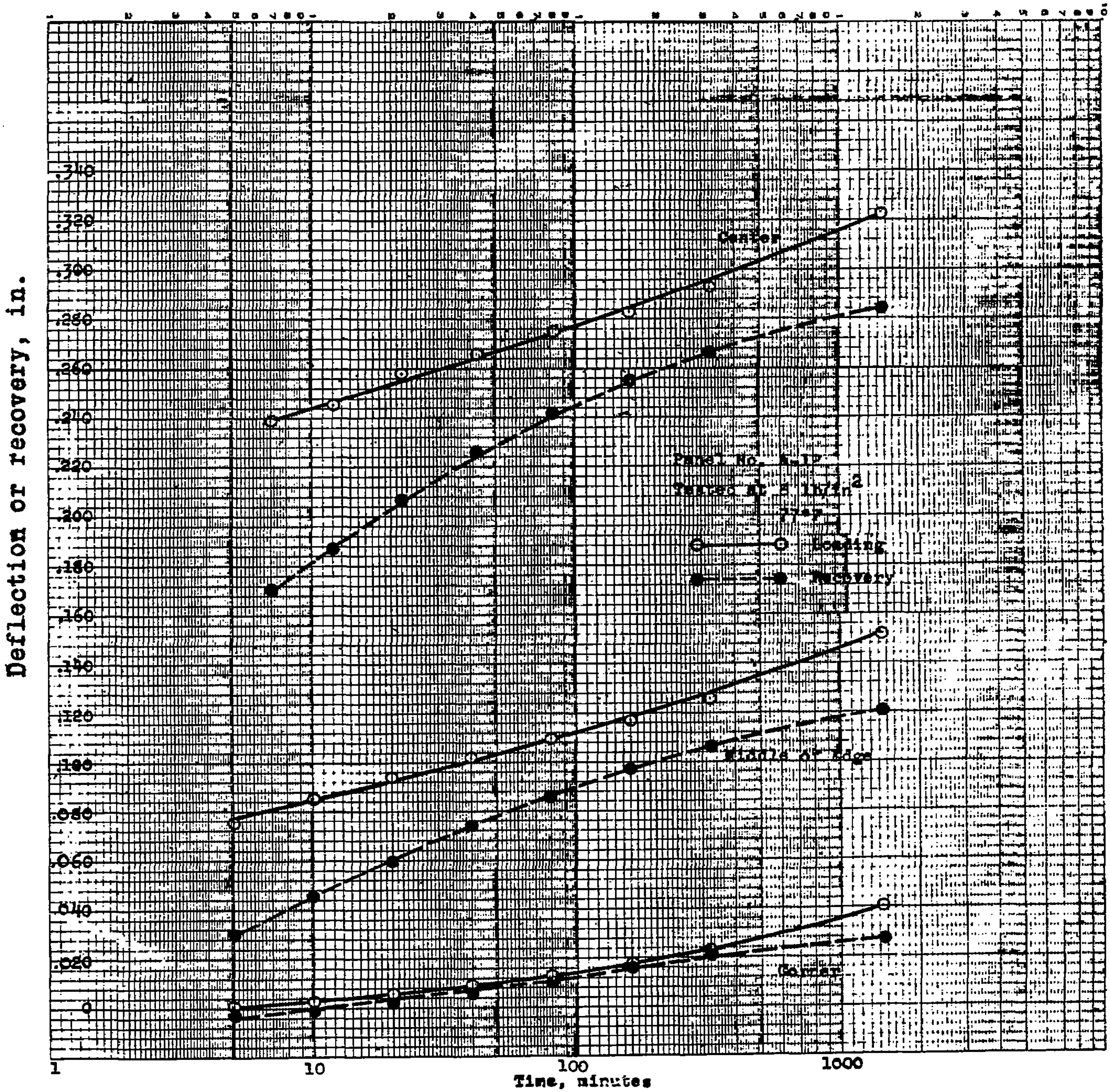


Figure 8.- Deflection-time characteristics during loading and recovery.

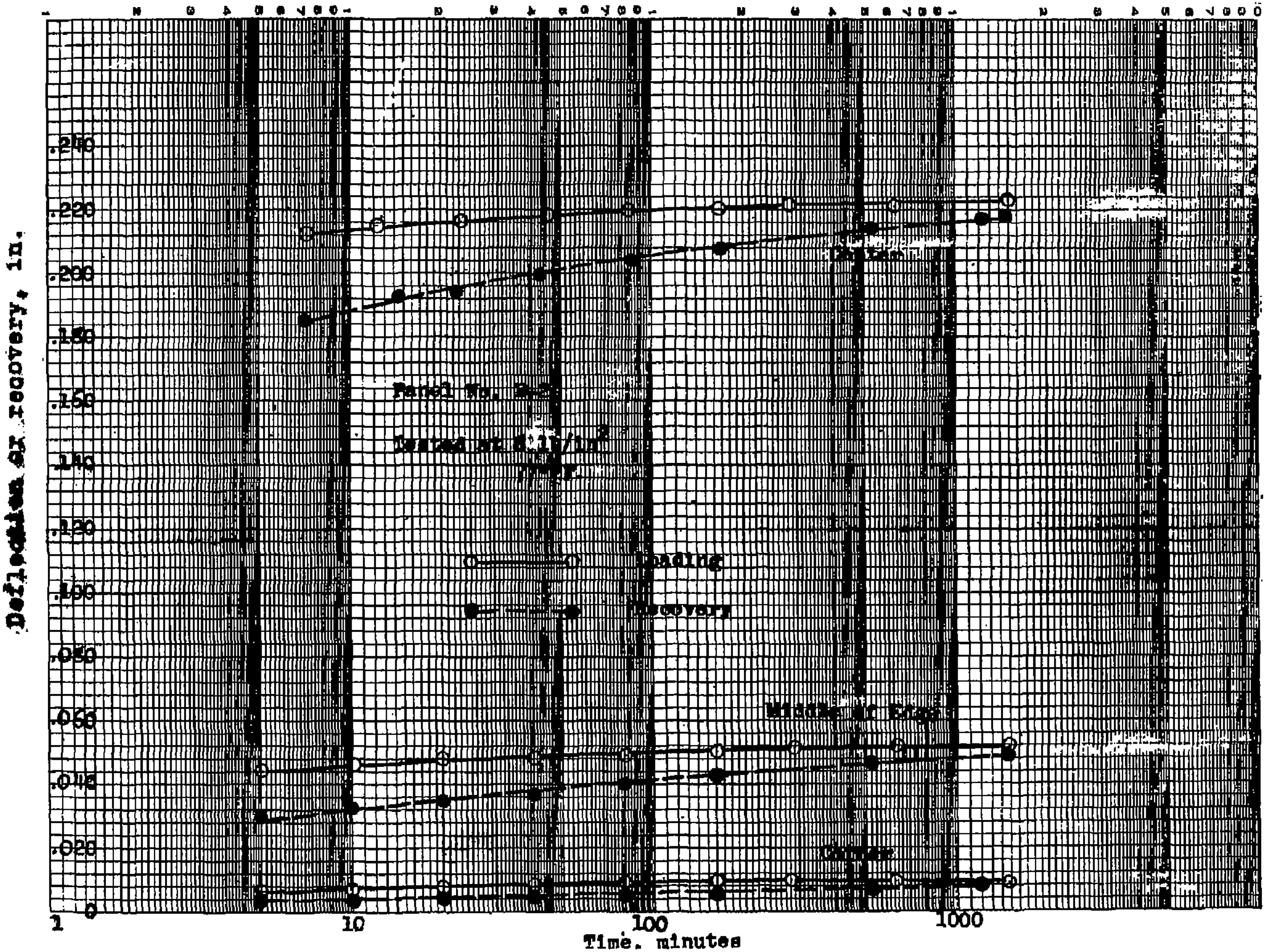


Figure 9.- Deflection-time characteristics during loading and recovery.

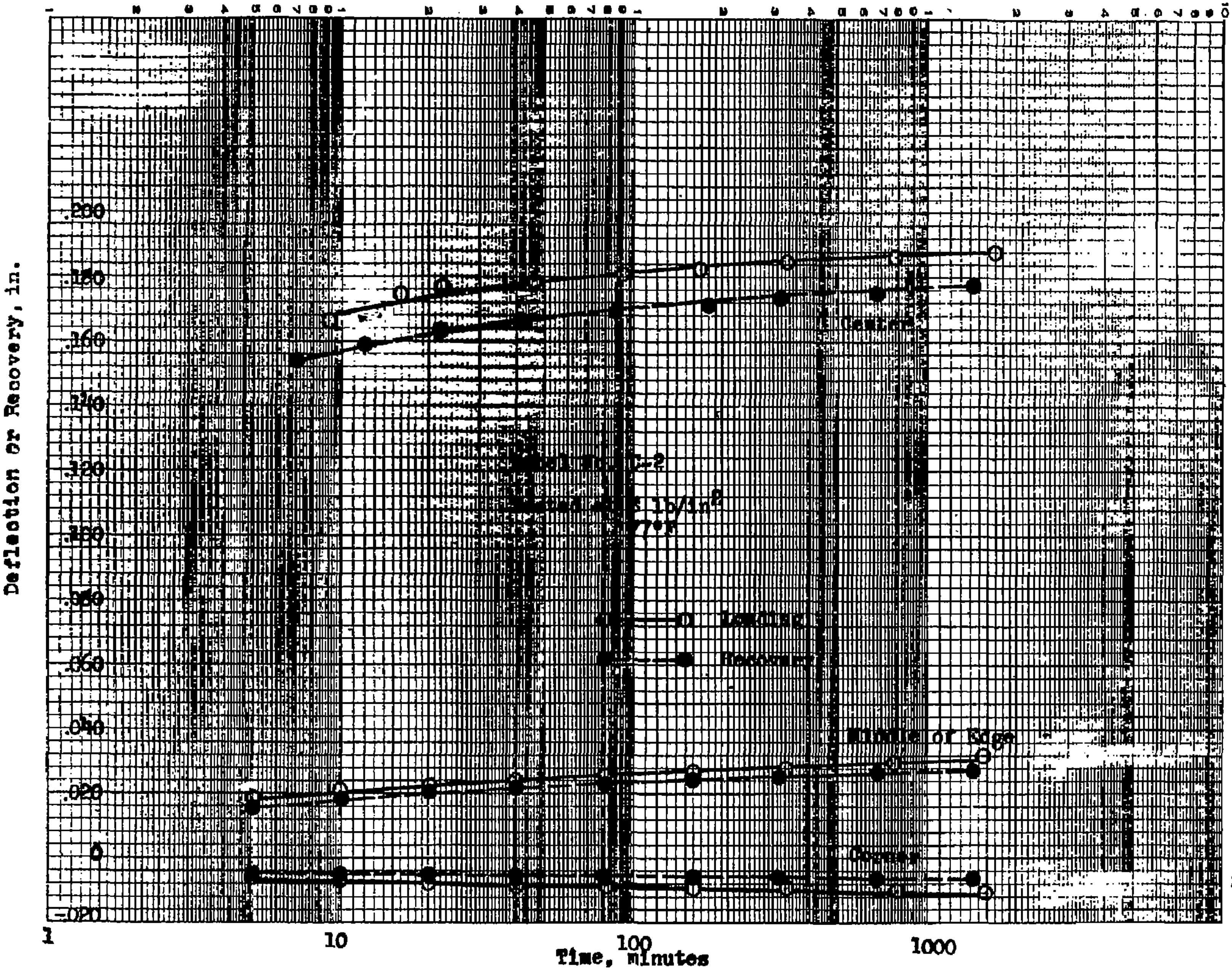


Figure 10.- Deflection-time characteristics during loading and recovery.

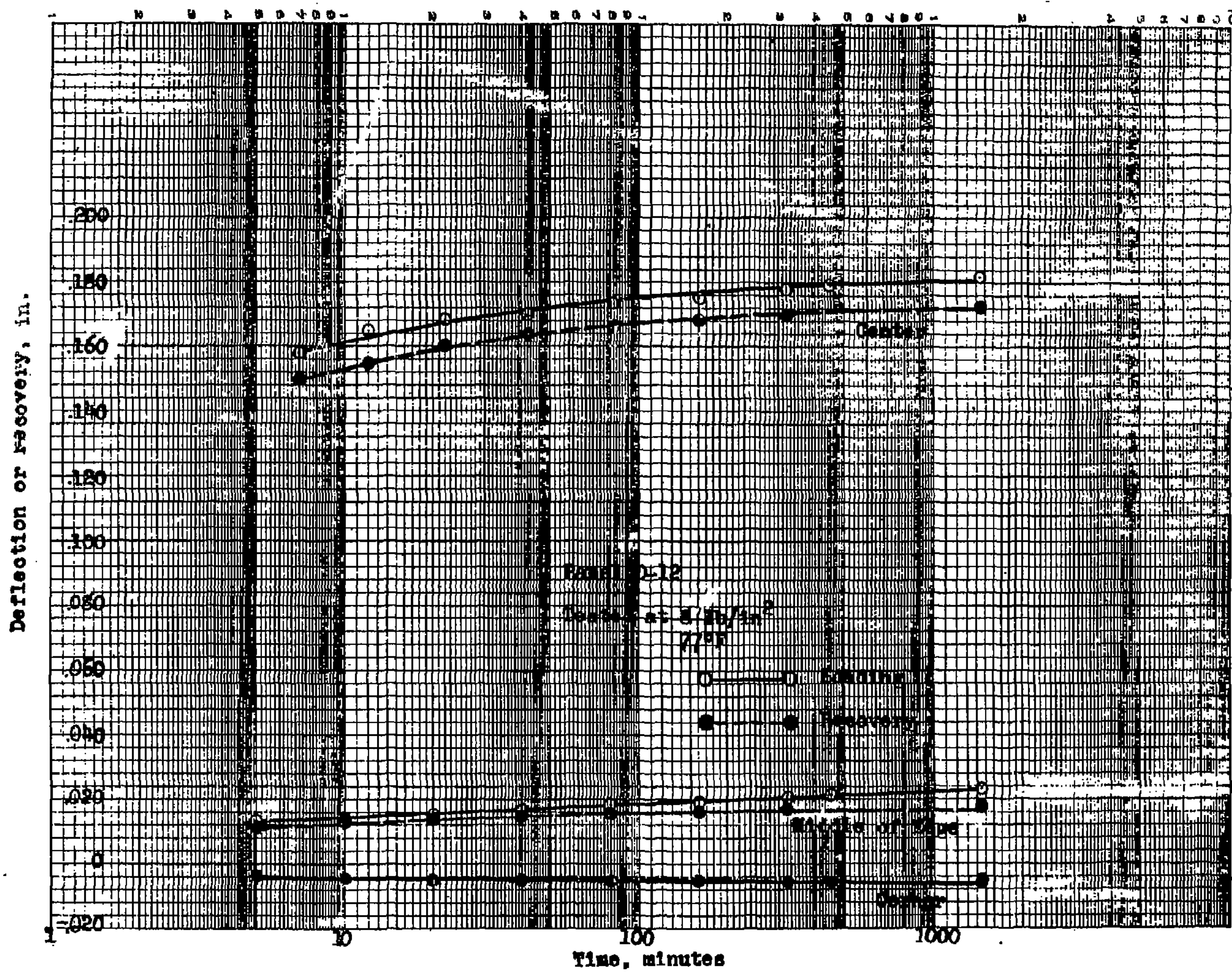


Figure 11.- Deflection-time characteristics during loading and recovery.

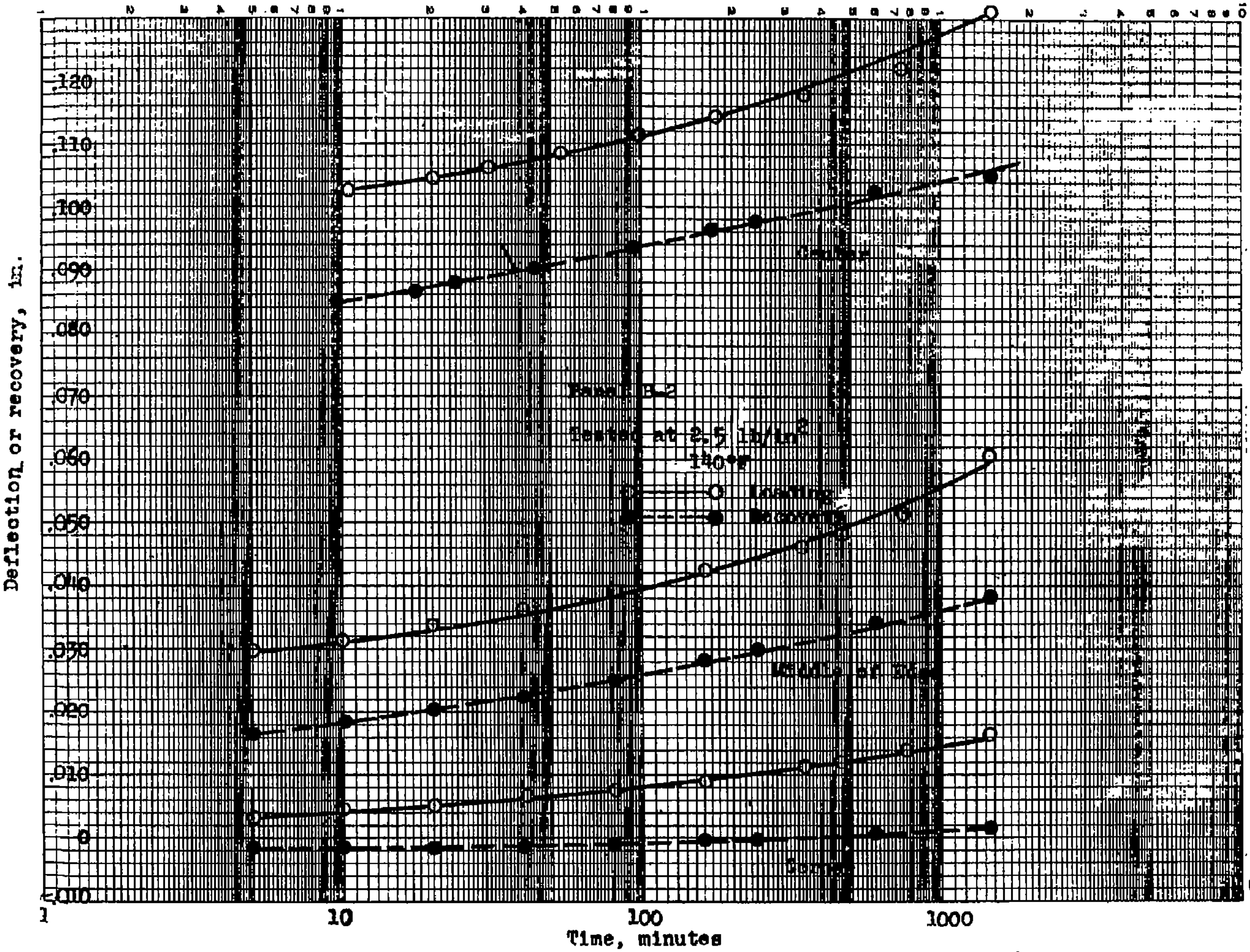


Figure 12.- Deflection-time characteristics during loading and recovery.

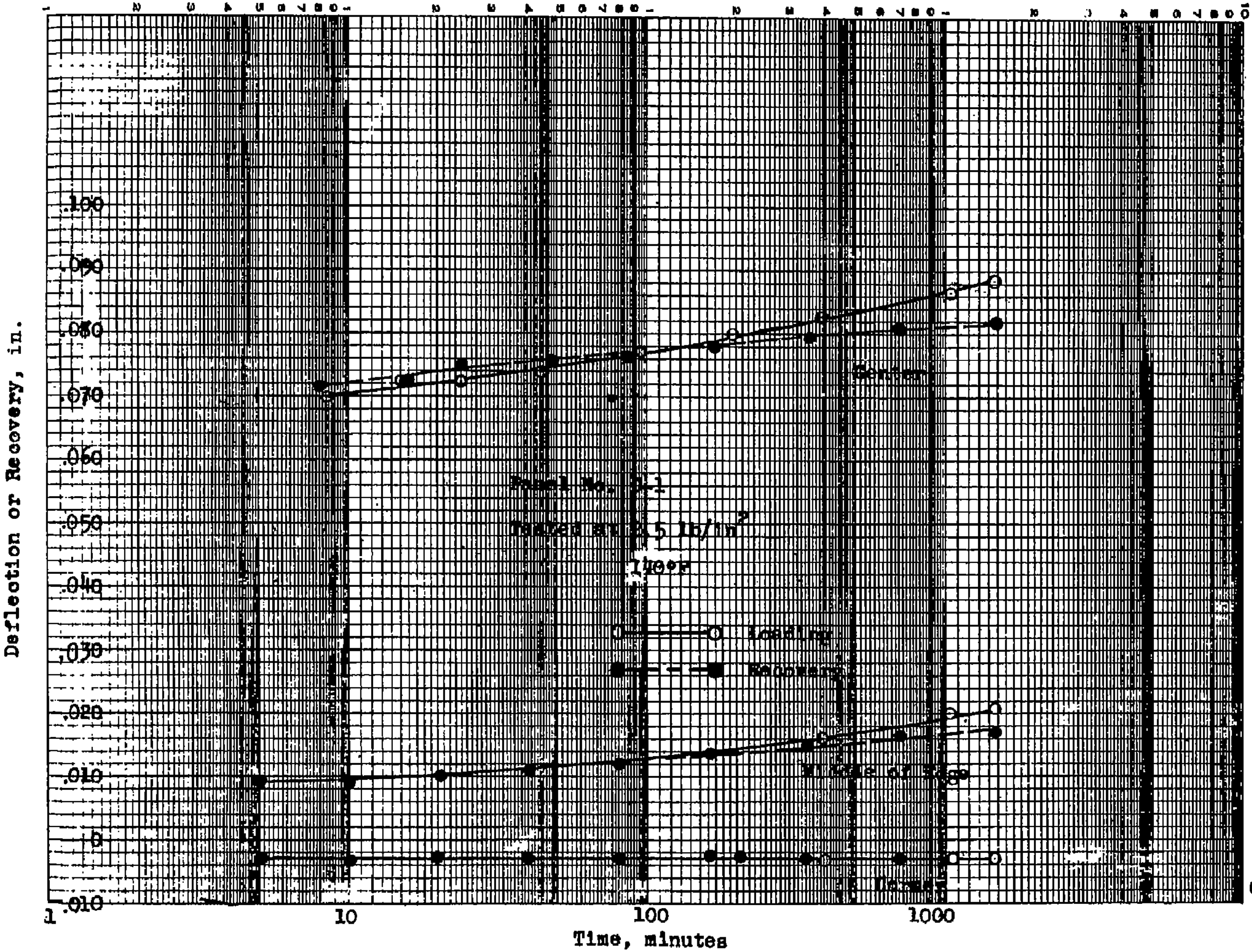


Figure 13.- Deflection-time characteristics during loading and recovery.

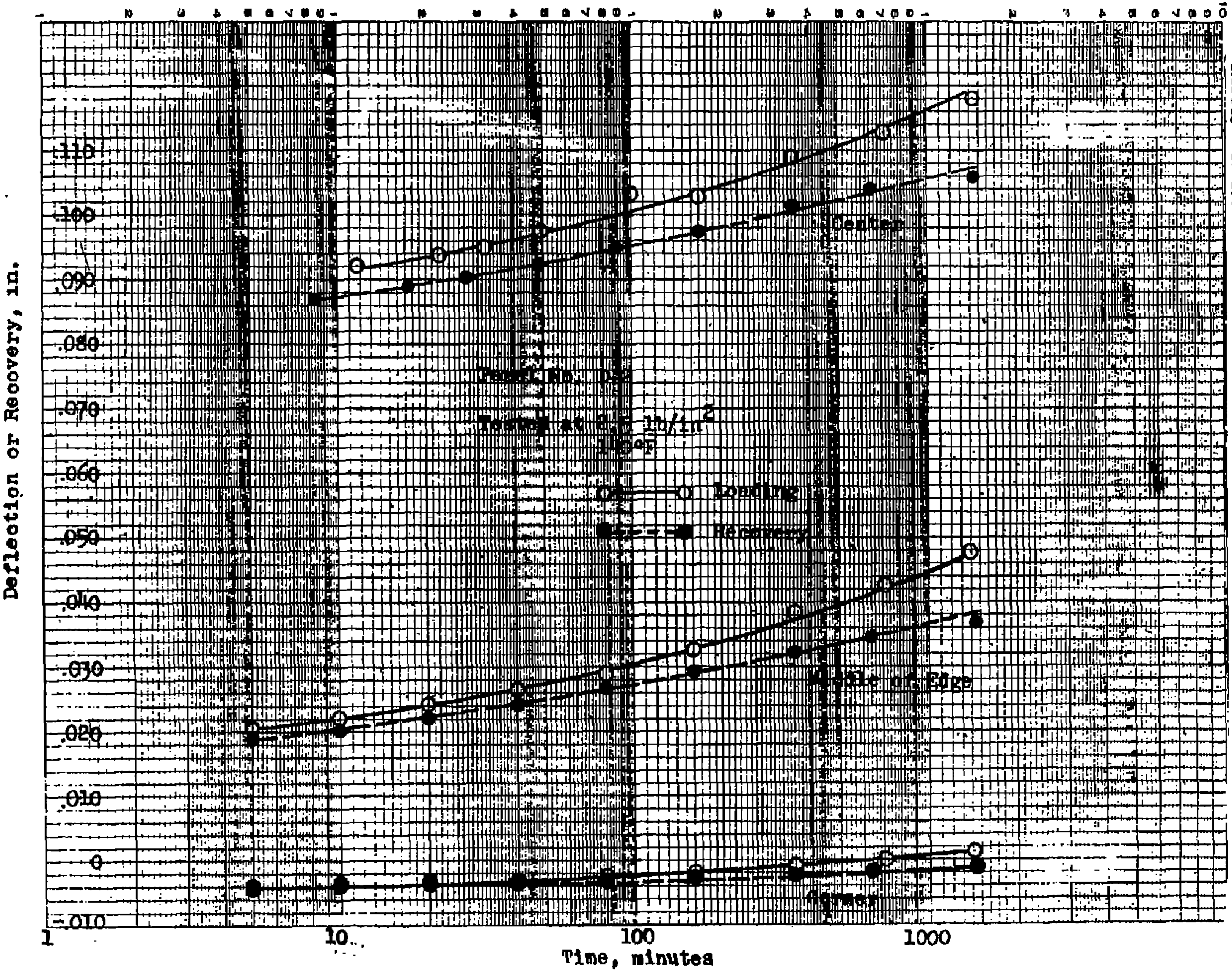


Figure 14.- Deflection-time characteristics during loading and recovery.

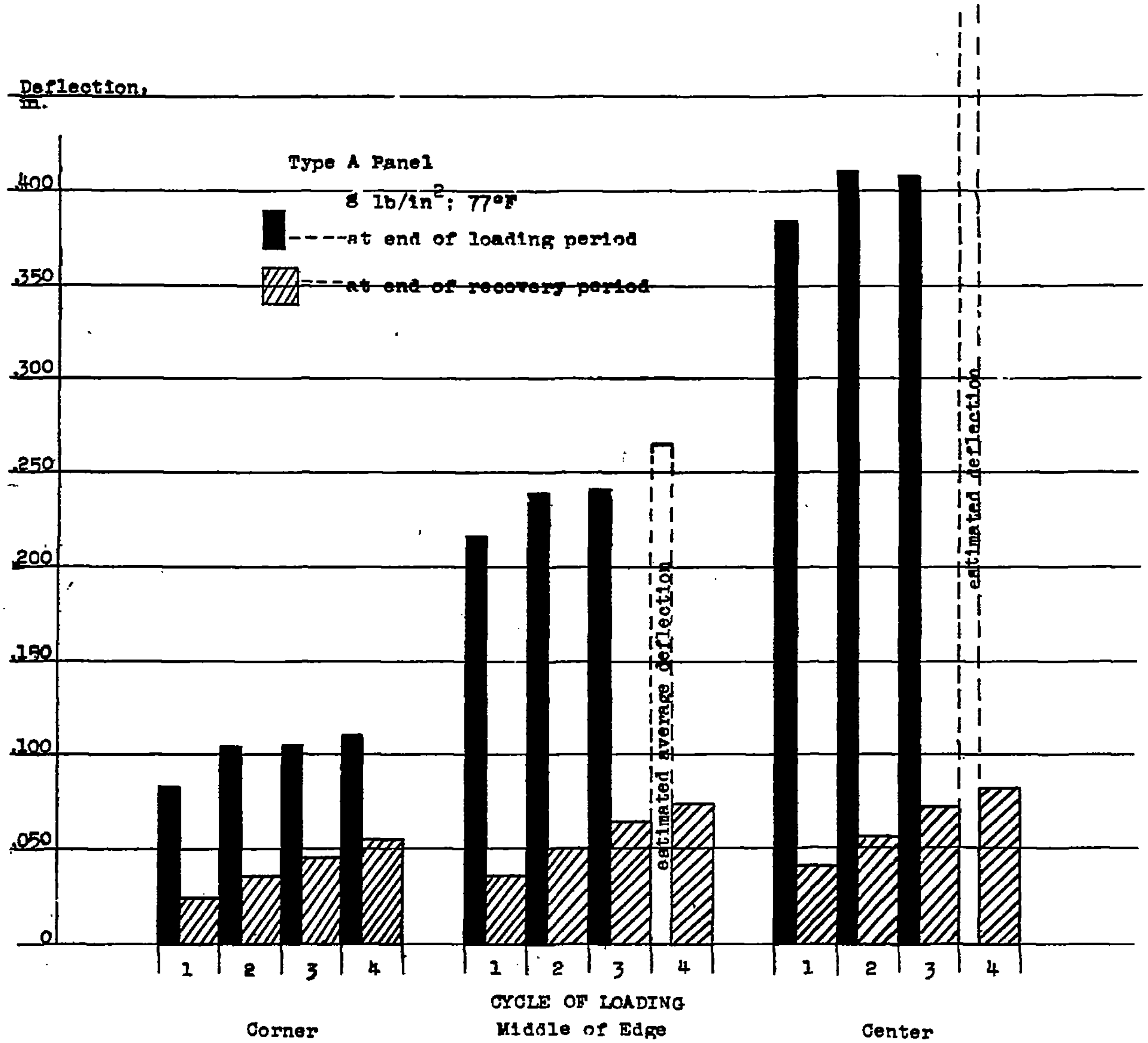


Figure 15.- Deflections measured in cyclic loading tests.

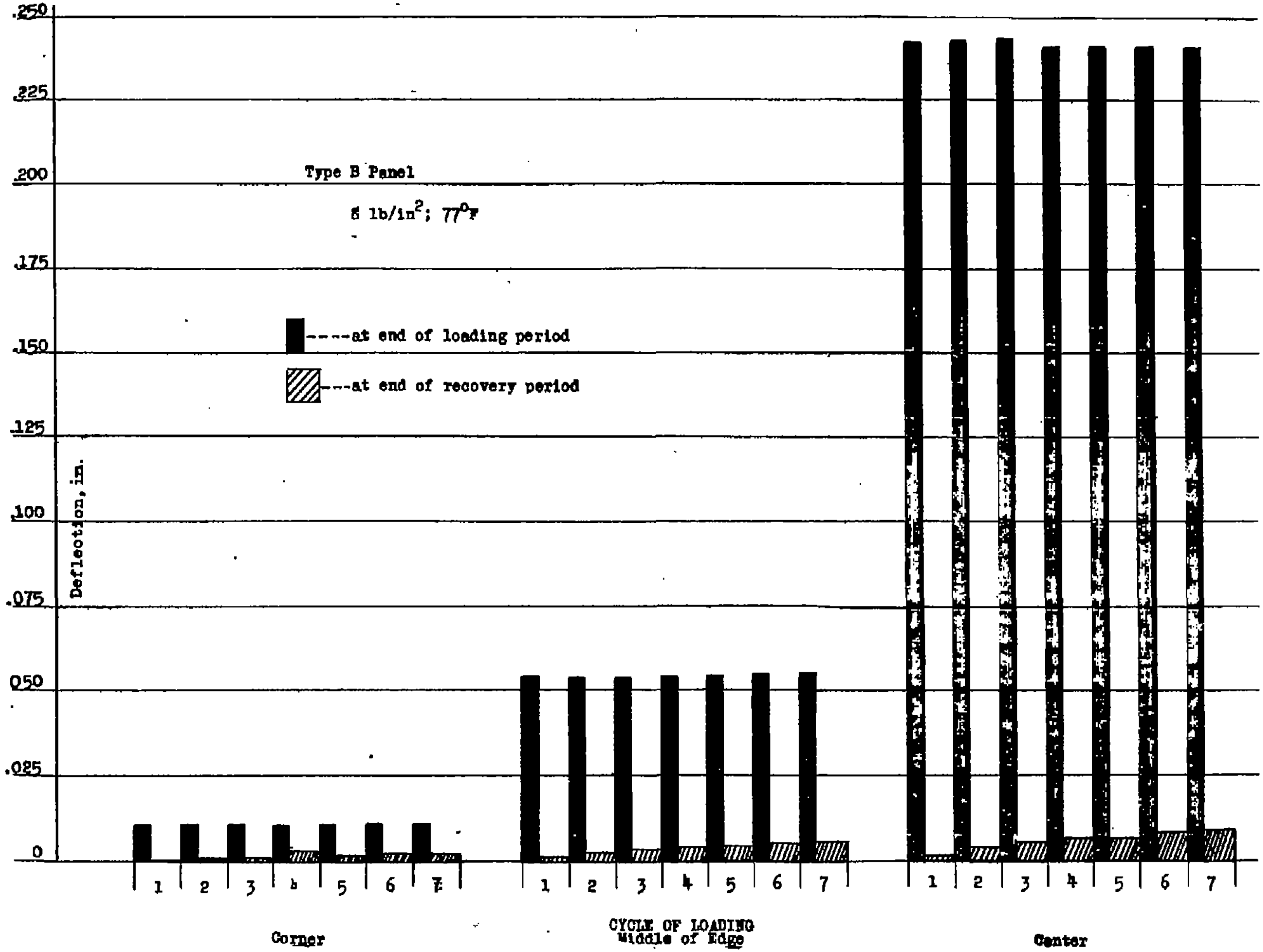


Figure 16.- Deflections measured in cyclic loading tests.

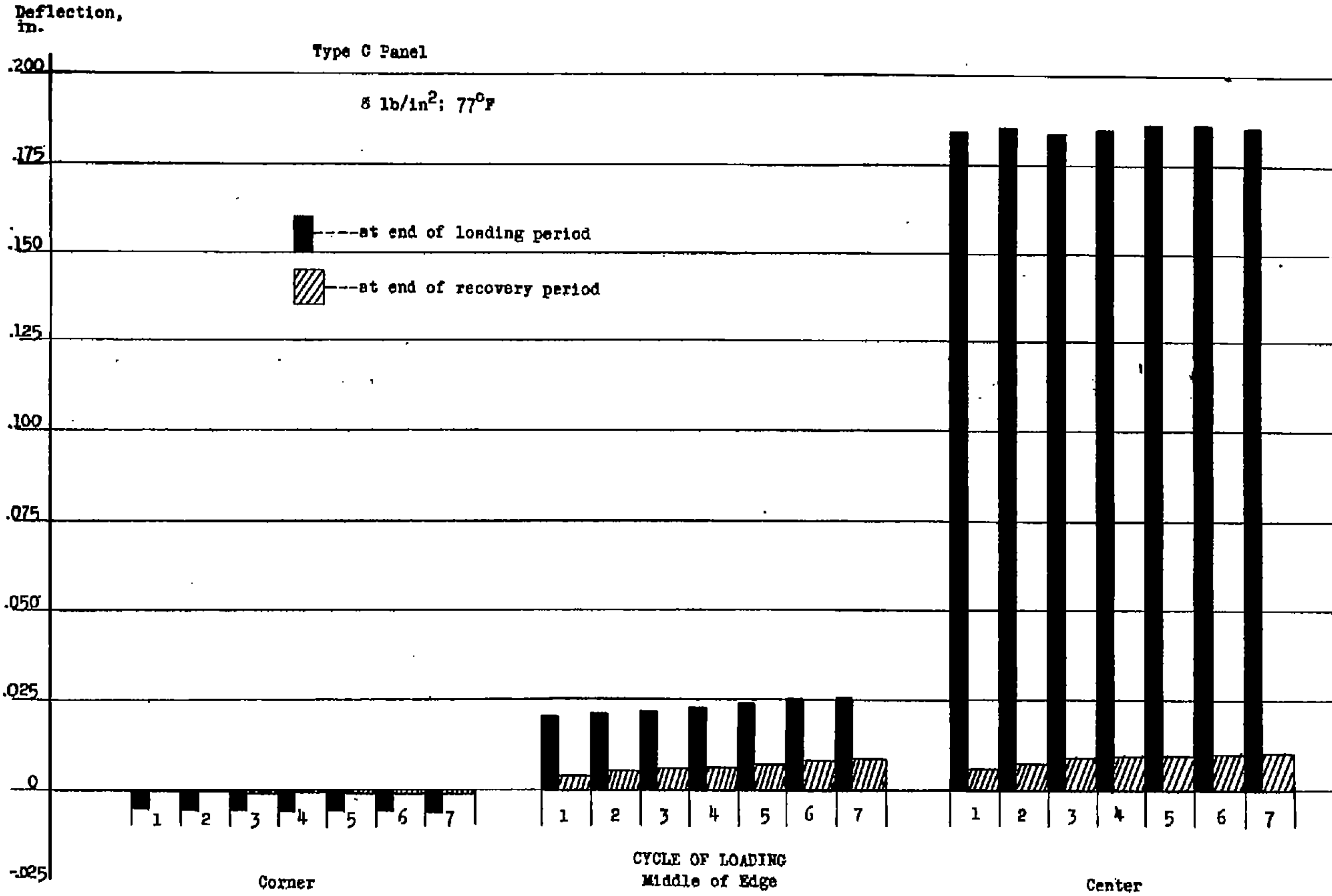


Figure 17.- Deflections measured in cyclic loading tests.

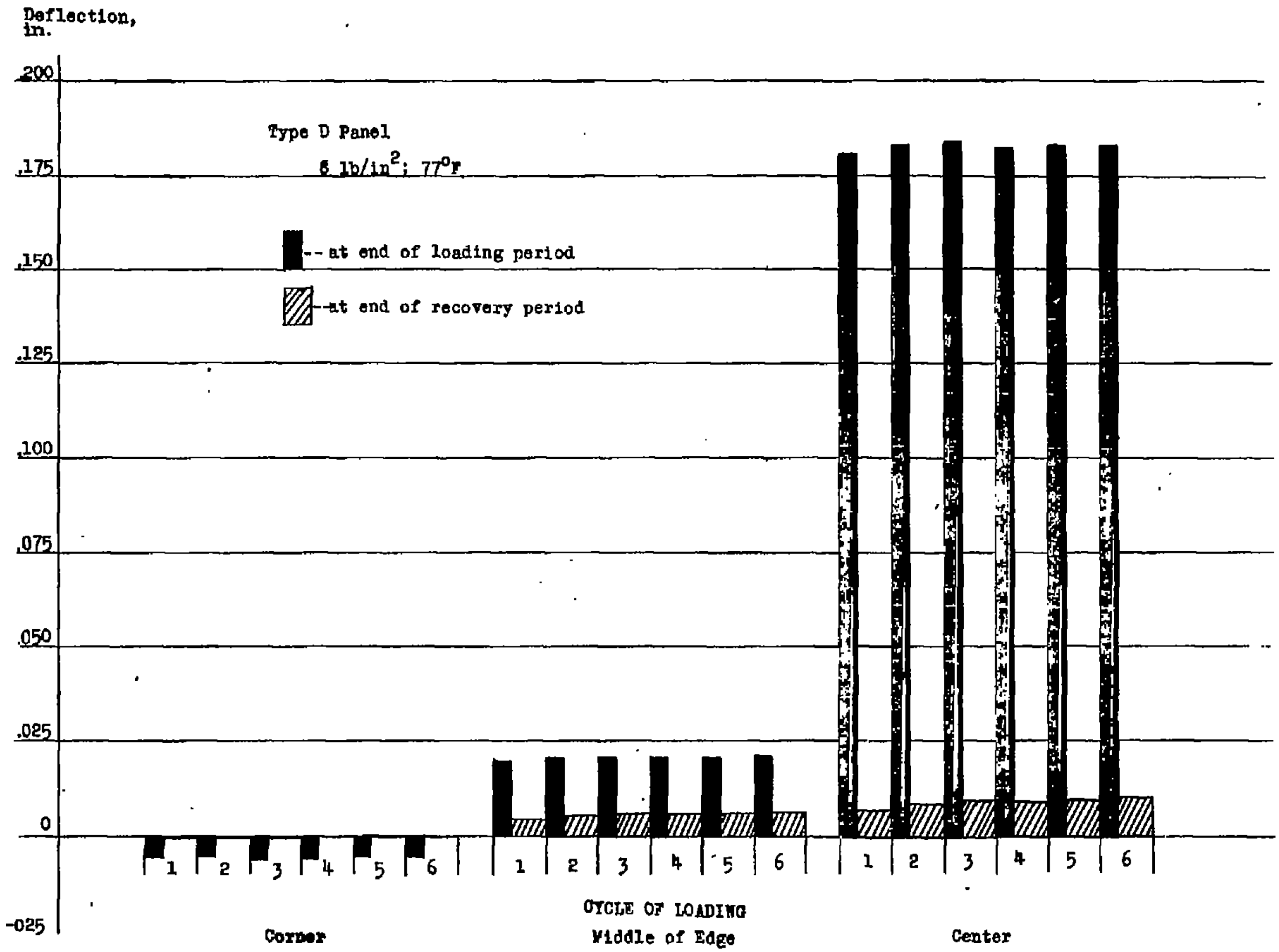


Figure 18.- Deflections measured in cyclic loading tests.

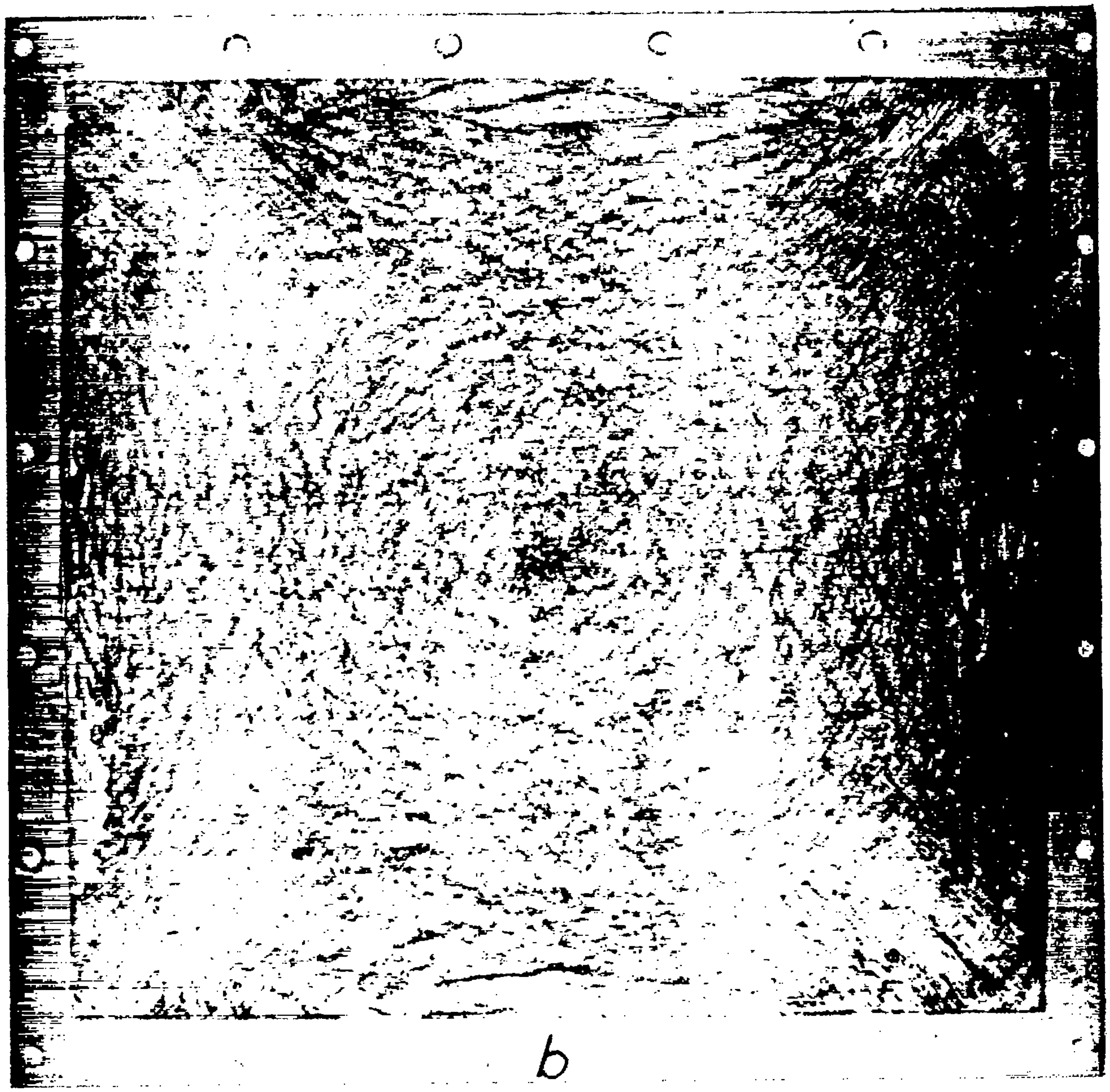


Figure 19.- Type A panel after bursting test at 77°F.

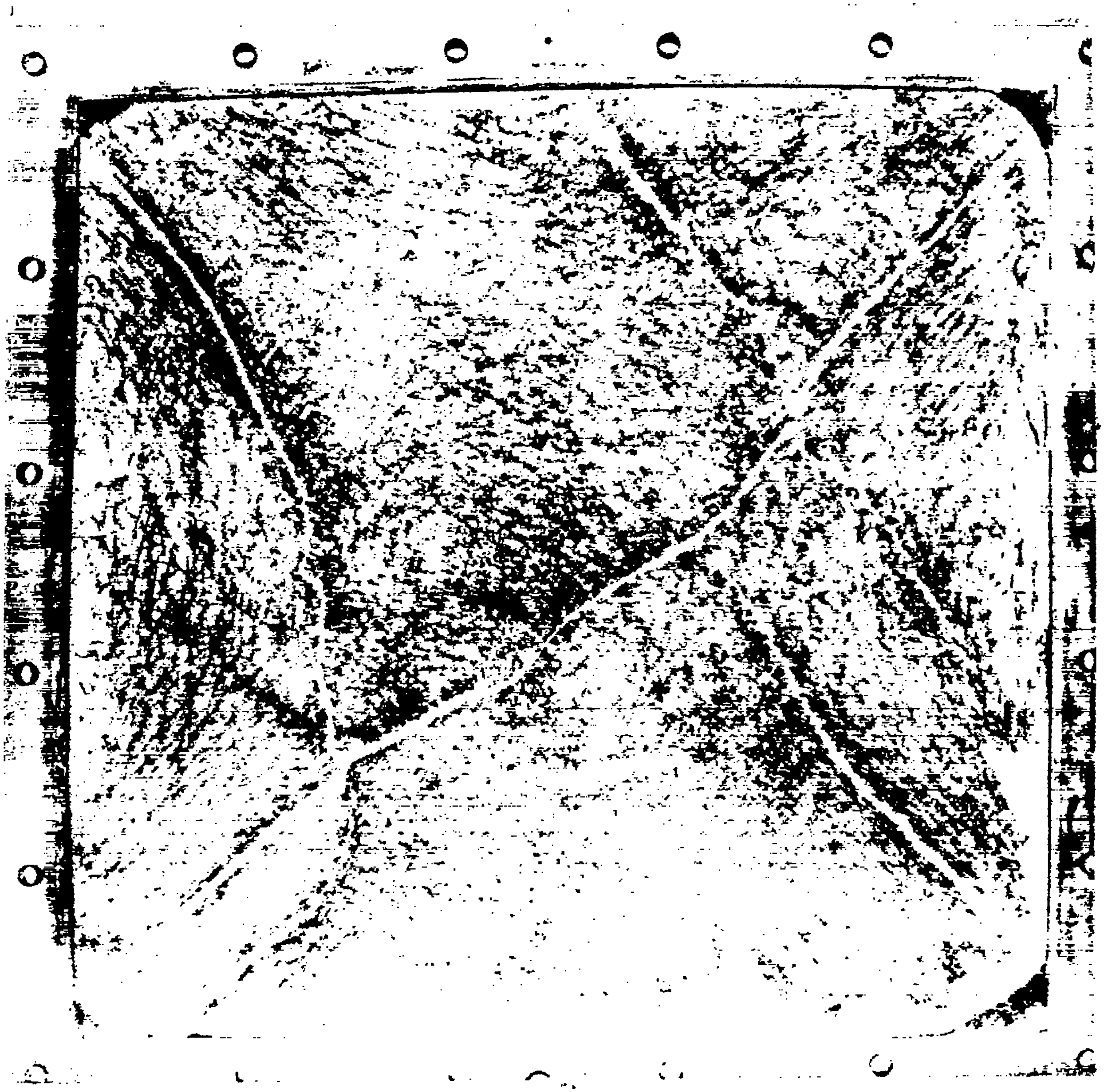


Figure 20.- Type A panel after bursting test at -20°F.

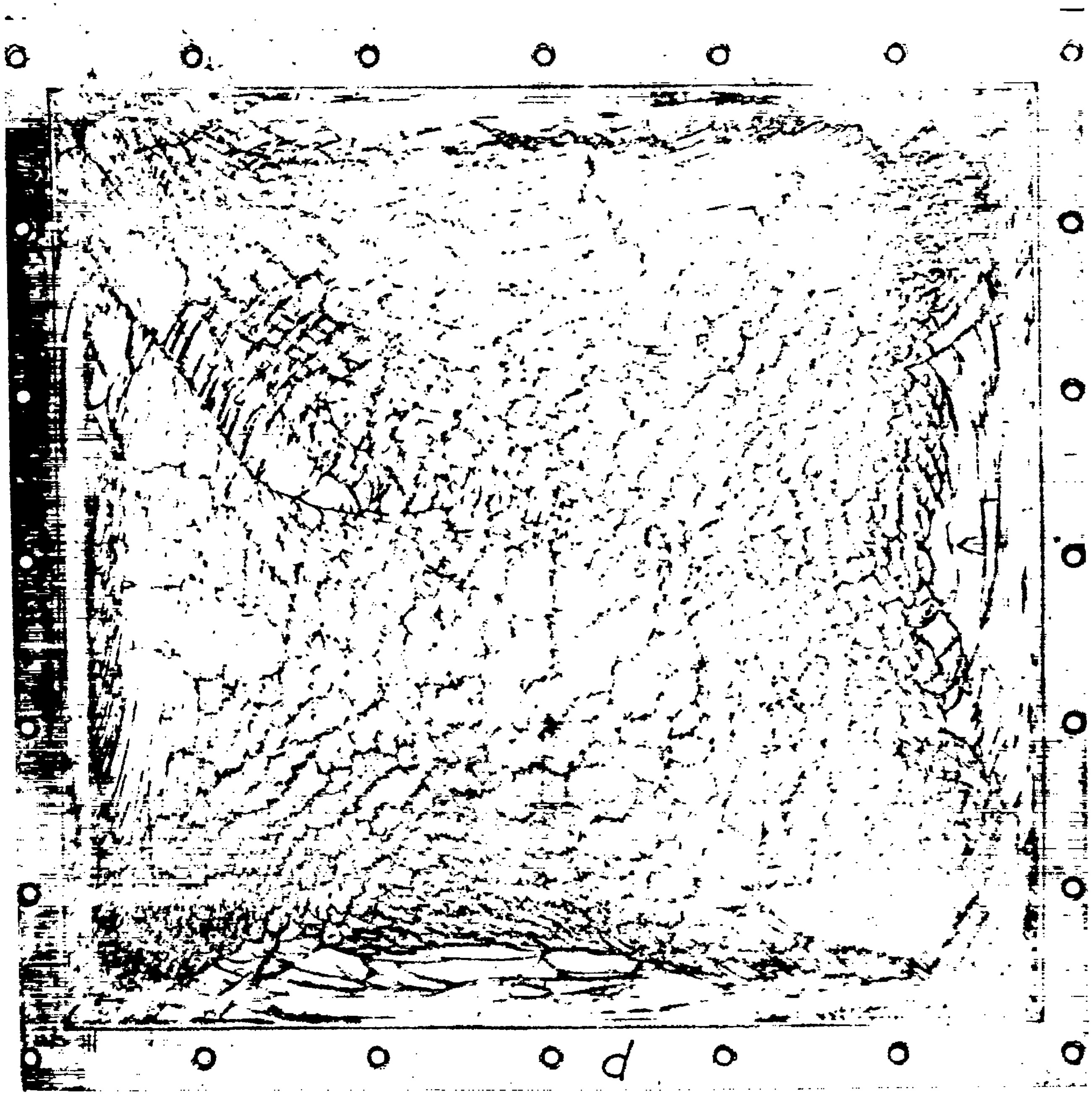


Figure 21.- Type B panel after bursting test at 140°F.

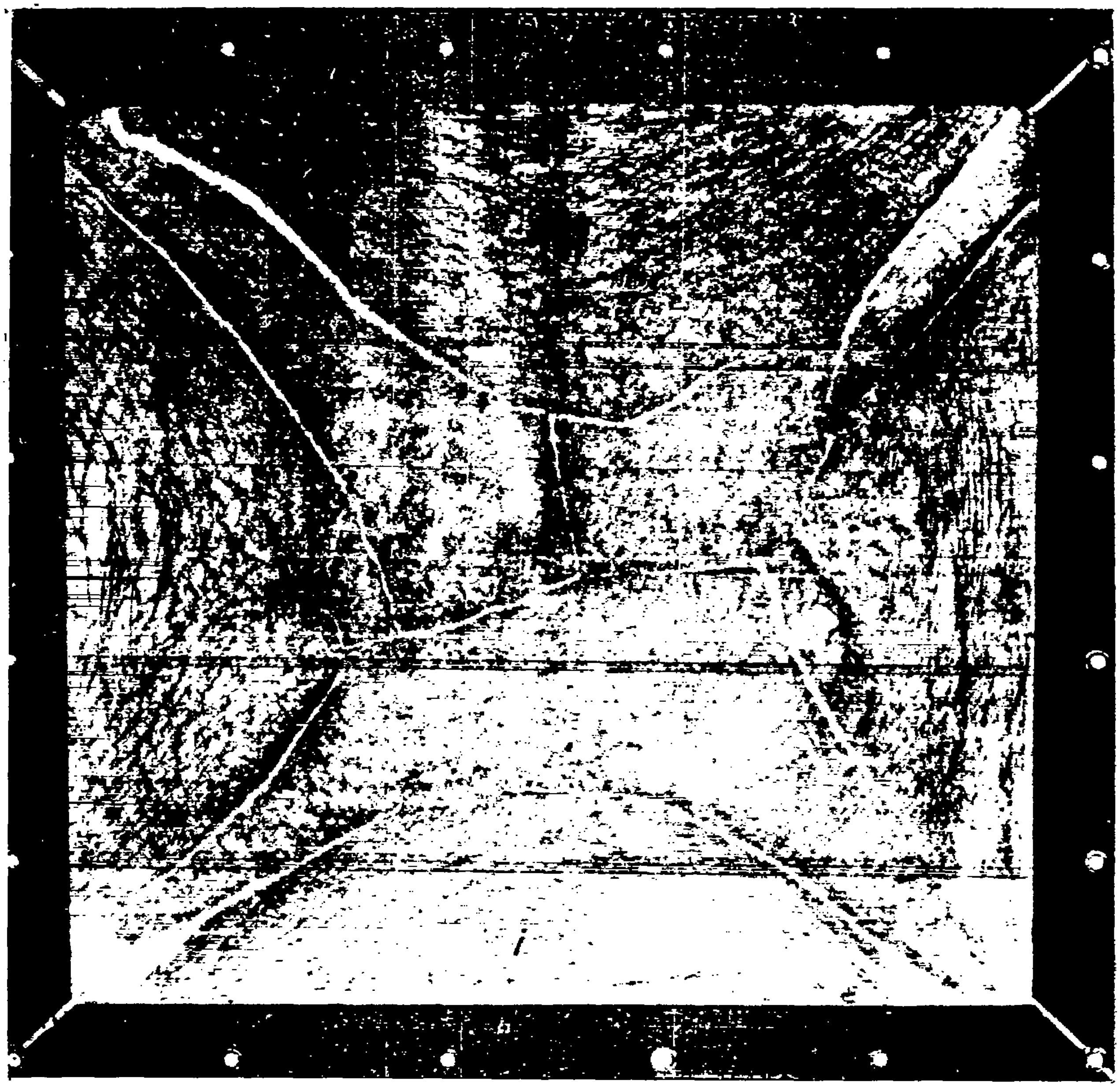


Figure 22. - Type O panel after bursting test at -20°F.

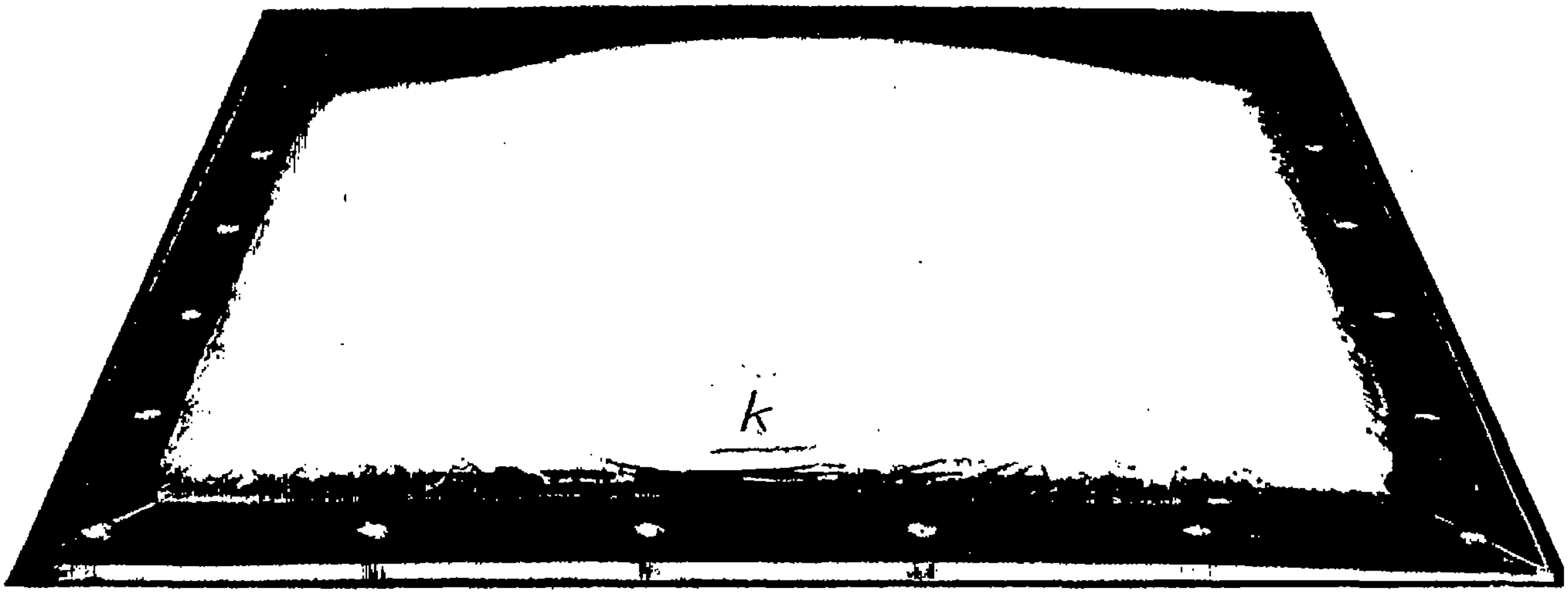


Figure 23. - Type D panel after bursting test at 77°F.